Xerography: an Invention That Became a Dominant Design

Mark B. Myers

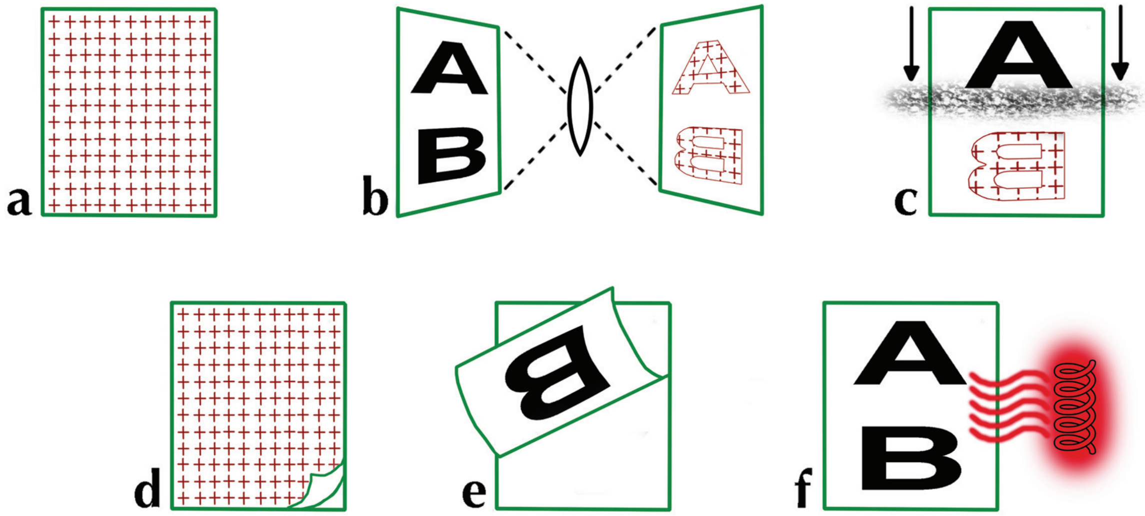
Introduction

Xerography, or electrophotography, was one of the great inventions of the twentieth century. It was invented in 1938, 78 years ago, and remains in wide use today. The copier has become a common presence in our workplace, and its availability is assumed. Prior to its invention an office worker would type an original with sheets of carbon paper and copy paper sandwiched behind it in the typewriter carriage. Legibility limited the number of copies that could be made. If more copies were required, the typing process would be repeated or a master would be typed and offset printing would be employed. The xerographic copier radically changed all of that work and created a whole new communication chain between office workers and their organizations with the multiple copies of a copy sharing the remarks of the respondents.

Xerography's creation and application closely parallels the 100-year history of The Optical Society. It was invented as a novel imaging system, which had no existing competitors. One of its first public demonstrations was at The Optical Society's Annual Meeting held in Detroit, Michigan, on 22 October 1948 [1,2]. Although seen as highly novel, the observers could not see the future value of the technology. That was not unusual: the leading industrial laboratories of the time had previously been offered the opportunity for the development and commercialization of the technology, but all had declined [3].

It would be 1959, owing to the combined efforts of Battelle Memorial Institute and the small company Haloid that would become the Xerox Corporation, when the Xerox 914 copier made its phenomenal market introduction. It would take the efforts of the inventor Chester Carlson, the Battelle Memorial Institute, and Xerox people over a period of 21 years to reach this 914 success—and what a success it was! It is estimated that in 1955 before the introduction of the 914 about 20 million copies per year were made worldwide, largely by typing carbons. In 1964, five years after the introduction of the xerographic copier, 9.5 billion copies per year were made, and in 1985 the number had grown to 550 billion [4]. The revenues of the small Haloid-Xerox Corporation based on the 914 and the follow on products would grow at a 44% rate compounded annually for the decade 1960 to 1970 to be greater than $1.5 billion. It was the fastest sustained corporate growth rate in history up to that time.

When invited to write this brief chapter on the history of the invention of xerography, the author was confronted with the question of what more can be usefully said that has not been previously written. Two comprehensive books were published on the subject in 1965 by the key early participants, namely, *Xerography and Related Processes* by John Dessauer and Harold Clark [5] and *Electrophotography* by Roland Schaffert [6]. There are at least four other texts [7–10] written by practitioners over the period 1984 to 1998 as well as numerous scientific papers and popular press reviews in the same period written by scientists who researched the key processes during the further development of the technology. The value the author brings is that of an early participant in the decade following the introduction of the 914. These are the observations of a young scientist joining Xerox in 1964 to work with the individuals from Xerox and Battelle who created that first product success.



▲ **Fig. 1** Six-step process.

The Invention

Xerography is a photoelectric imaging process that creates high-fidelity copies. It is distinguished for its ability to image directly onto plain paper without the use of wet chemical agents, which were common to silver halide and other sensitized paper photography. How xerography works is demonstrated in the following six-step process (see Fig. 1.):

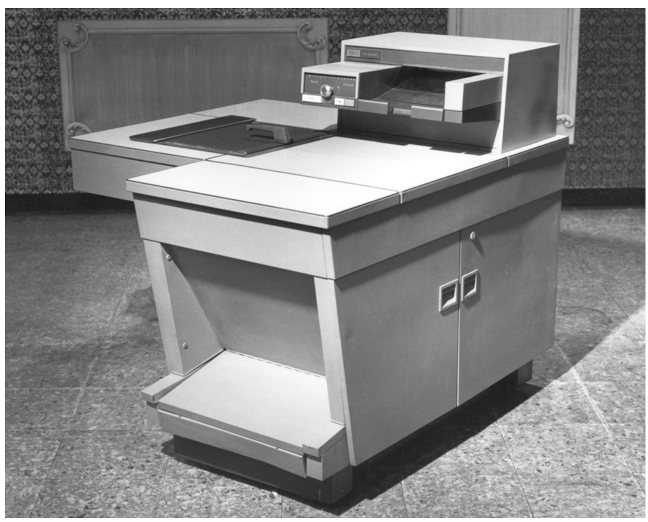
1. An insulator photoconductive sheet attached to an electrode substrate is uniformly electrostatically charged.
2. The photoconductive sheet is imagewise exposed with light. The electrical conductivity of the photoconductor's exposed areas is greatly increased and the surface charges are discharged through the photoreceptor, leaving a latent electrostatic image on the unexposed areas.
3. Pigmented polymer particles charged to the opposite polarity of the latent image are cascaded over the surface. The pigmented particles are electrostatically attracted and tacked to the charged image area, whereas the particles do not stick to the uncharged areas. The latent image is now visible.
4. Plain paper is placed on top of the powder image, and a charge is applied to its back surface with sufficient voltage to de-tack and transfer the image to the plain paper.
5. The plain paper is stripped away from the photoreceptor surface with the image.
6. The polymer toner image on the paper is fused by heat. The photoreceptor surface is cleaned and readied for the next imaging.

This six-step process is the formulation of the basic Chester Carlson 1938 invention as filed in his patent application of 4 April 1939 and which was issued in 1942 [11]. The process has been so robust over time that it still is the core design of all xerographic copiers and printers produced, 77 years later.

The first commercial implementation of this process was the Xerox Model A processor introduced in 1949 (Fig. 2). It was a totally manual operation where the operator carried out each of the above process steps. As a new Xerox employee, the author was introduced to xerography with this machine by working through all of the steps described above. The experience was reminiscent of an introductory physics lab, interesting to the technically trained but bothersome for office workers.

The time between these products, 1949 to 1959, required intensive improvements by the Battelle and Xerox teams in both process physics and materials. The major new challenge to realizing the potential of this technology was the automation of the process steps requiring their systems integration and the creation of a manufacturing capability for these new machines. The operating advances by the engineers were remarkable. The 1949 Model A could produce one copy every four minutes in the hands of a skilled operator. The 914 would produce seven copies per minute with a press of the "green" button in 1959 (see Fig. 3). In 1968, the Xerox 3600 would produce copies at 60 pages per minute, or one every second. The automated xerographic six-step process is shown in Fig. 4.

▲ **Fig. 2.** Xerox Model A, 1949. (Courtesy of Xerox Corporation.)



▲ **Fig. 3.** Xerox 914, 1959. (Courtesy of Xerox Corporation.)

The Inventor

Chester Carlson by every measure is the model for the aspirations of all independent inventors: he created a great invention that had tremendous societal benefits as well as providing him with great personal wealth. He is the individual inventor's dream.

His story is compelling. He grew up as an only child in a family of very limited resources. In his early years he became the sole provider for his parents. Living in a suburb of Los Angeles, he worked his way through two years at the Riverside Junior College, from which he transferred to California Institute of Technology for his final two years and graduated with a degree in physics. He started his career in Bell Labs in New York, but was laid off during the depression. He became a patent attorney after attending the New York University law school. It was his work as an attorney that drove his sense of purpose to find a solution to the need for copies.

Chester Carlson first filed a patent application for his invention in October 1937 and reduced it to practice in October 1938 reproducing the image "10–22–38 ASTORIA." At this time he had funded an assistant, Otto Kornei, to help with the laboratory work. This experimental process was his basis for working out the basic six-step process that was the core of his invention. The photoconductor they employed was amorphous sulfur, and they developed the image with dyed lycopodium powder. Charging was done by rubbing a cloth imparting a triboelectric charge on the sulfur film and shaking the powder in a container to impart a triboelectric charge of the opposite sign. The developed image was fused by heat from a Bunsen burner.

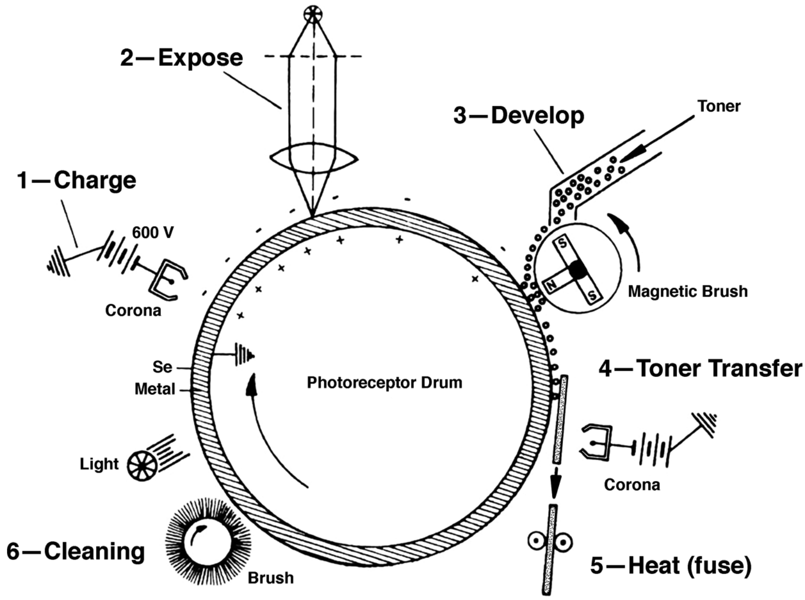


Fig. 4. The automated xerographic process using the six-step process. In brief, the original is scanned and projected synchronously onto a charged rotating photoreceptor drum. A toner development station develops the image on the photoreceptor and the copy paper is fed to transfer the image from the photoreceptor. The image is detached from the photoreceptor and then passed through toner fuser rolls.

Chester Carlson would contact over 20 companies to try to establish interest in his invention over the period of 1938 to 1944, with no success. In 1944 he had the opportunity to describe the invention to Russell Dayton of the Battelle Memorial Institute. Dayton was visiting Carlson seeking counsel on an unrelated patent matter and became interested in the idea. Battelle and a yet to emerge small company, Haloid, would transform his ideas into a phenomenal success.

Working with both of these organizations, Carlson would relocate to Rochester, New York, and make the Haloid (to become Xerox) labs his professional home. He would maintain an office there through the 1960s. His original xerographic patent would expire in 1955 just before the introduction of the 914. He actively protected his and Xerox's interests by filing over 20 additional xerographic patents, with the final one granted in 1965. The author recalls his presence in the labs. He was a highly honored figure for the new and growing research staff. He was very shy, so few knew him well personally. When he was seen walking the hallways, on second glance he would be gone, a ghostlike figure.

Chester Carlson's wealth from his invention would reach $150 million. At the time of his passing in 1968, that amount would be worth over $1 billion in today's money. He spent the final period of his life giving away his wealth to causes that supported peace and social justice.

Battelle Memorial Institute

Carlson was invited to come to Columbus, Ohio, to demonstrate the concept to members of Battelle's management and research staff, and although the invention was in a very early state, they were interested. A working agreement was concluded in 1944 for Battelle to undertake the development of xerography for a license on future revenues. The Battelle researchers undertook the investigation and selection of the key technology components of the six-step process to enable the system to work. Key advances were the use of amorphous selenium as the photoreceptor, the design of corotrons for the charging processes, and the invention of the two-component development and fusing systems to fix the image.

Battelle was innovative both in their research and in their willingness to break their own business model. They were a contract research organization to which clients brought their problems and purchased the necessary research and development. Battelle did not fund research on ideas from outside inventors, but they changed this in the case of Carlson and xerography. In a sense they were modeling a role that venture capitalist investors would play much later. They would address the challenge of getting to market by forming a partnership with Haloid in 1947. The rights that had been acquired from Carlson would be sold to Haloid for an equity position in the growth of the business. Battelle additionally gave exclusive rights to the xerographic patents that they had been granted from their development efforts. At the conclusion of the Battelle and Xerox relationship in 1970, Battelle had increased the wealth of their endowment manyfold.

The Haloid Company (to Become Xerox)

In 1944, John Dessauer, the head of Haloid research, and Joseph C. Wilson, who would soon assume the Haloid presidency, were looking for new directions for the company. Dessauer came upon an article describing electrophotography in the July 1944 addition of the *Radio News*. He shared the article with Wilson, and they agreed that a closer look was warranted.

▲ **Fig. 5.** Dr. John Dessauer, Haloid head of research to the left, Chester Carlson, and Joseph C. Wilson, president of Haloid, examining a xerographic printer prototype in the late 1940s. (Courtesy of Xerox Corporation.)

Haloid was a small Rochester, New York, company formed 1906 by a group of individuals who had left Eastman Kodak (see Fig. 5). For many years they had a small but successful business producing high-quality specialty silver halide photographic paper. They operated in the shadow of the much larger Kodak Company, which limited their growth potential in photographic paper. In time, other competitors eroded the competitive advantage of their specialty product. The future of Haloid was in doubt, and they needed a new vision and marketplace.

John Dessauer and Joseph C. Wilson, the soon-to-be president of Haloid, visited Battelle in Columbus, Ohio, in December 1945 to see the technology demonstrated. They approached Battelle early in 1946 to request an exclusive license to the technology and to propose a joint development program. Battelle most probably would have preferred a more promising partner, but they, like Chester Carlson, had not found any company interested. An agreement was reached to take effect 1 January 1947.

Joseph C. Wilson was the head of Haloid and Xerox in the period 1946 to 1967. He was from a wealthy Rochester family and was the third in the line of Wilsons to be the head of Haloid. He graduated from the University of Rochester, where he studied literature, and received an MBA degree from the Harvard Business School. He was an exceptionally eloquent business speaker. He loved poetry, and many of his speeches would either begin or end with a poem by Robert Frost.

He also was a man who was willing to take actions that had large risks. The Haloid Company represented most of his family's wealth. He invested $12.5 million in the 914-product development, which amounted to all of the company's profits for a decade, and he borrowed more. If the 914 had failed, the company would have gone under. After the great success of the 914 he would speak of one of the few disappointments. He spoke of friends who had offered to invest money for the development and how they would later be unhappy with him because he declined their offer as he felt that the risk of failure was too great. He is honored at the Harvard Business School by named chair, the Joseph C. Wilson Professor of Entrepreneurship.

John Dessauer was a chemical engineer, educated in Germany, who had immigrated to the United States in the 1930s as a result of the social upheavals that were taking place in his native country. He joined the Haloid Company in 1935 as part of an acquisition that the company had made. He became the first director of research for Haloid, and it was his insight that brought Chester Carlson, Battelle, and Xerox together.

John Dessauer would make another important contribution to xerography. Over the period 1960 to 1970, he would start the building of a Xerox research organization in Webster, New York, dedicated to evolving the company from the dependence on a core xerographic technology based on speculative invention to a predictive science base. The Xerox scientists and engineers would be challenged by the lack of relevant information to support increasingly sophisticated applications of the technology. The underlying sciences of triboelectricity, photo-generation, and charge transport in wide-bandgap semiconductors, controlled corona discharge in ambient atmospheres, physics of surface charge states, and the thermal flow characteristics of pigmented polymers were not widely practiced in the external scientific research of that time.

John Dessauer showed a personal interest in the new research recruits joining the organization. He would drop into the individual scientists' labs to establish connection through wide-ranging conversations. Dessauer developed a close consultative relationship to guide his organization building effort with John Bardeen, Nobel Laureate, of the University of Illinois, who served as an advisor and who would become a member of the Xerox board of directors from 1961 to 1974.

The research capability would continue to grow under the leadership of Jack Goldman, George Pake, and William Spencer with the establishment of Xerox PARC and Xerox Research Center of Canada. From 1981 to 1991, the work of the three centers would rank Xerox among the ten most influential academic and industrial research institutions in the United States as measured by reference to their scientific papers [12].

Xerography, a Dominant Design

Xerography has shown the characteristics of a dominant design [13]. Early in its history it established a competitive edge with respect to alternative technologies, thus becoming the customer and industry choice. Many competitive firms became committed to its usage, offering improved versions. Finally, the technology has shown the capacity to grow in capability and not hit limits leading to early obsolescence.

This does not mean xerography did not have serious competition from alternative technologies. Many organizations including Xerox invested in copying and printing technologies that if successful could have become replacements. They included drop-on-demand inkjet, continuous-stream ink jet, photoactive pigment electrography, and ionography. They all had merits, but only the drop-on-demand inkjet had major market impact. In the drop-on-demand inkjet case, it was a new market for color digital photography home printing that drove the demand. It was a market in which xerography would not be competitive.

A number of market and technological factors have greatly extended the useful life of xerography. The following key events are suggested:

- There was a benefit to the expansion of xerography by offerings of new competition. Xerox established through its relationship to Carlson, Battelle, and its own investments a patent position that limited competitive offerings. This patent exclusion was set aside in 1974 by a consent decree agreement with the U.S. Federal Trade Commission. It required that Xerox license to all competitors its xerographic patents for period of ten years and any new patents issued in that interval. This created an explosion of competitive offerings particularly from Japan.

- An important advance in 1969 was the invention of computer-driven laser writing onto a xerographic photoreceptor [14]. This opened a new market for xerography in electronic imaging and printing. Xerox introduced the 9700 in 1977, which printed single-sheet, 300-spi (samples per inch), single-sheet images at 120 pages per minute. Hewlett Packard introduced desktop laser 300-spi printing in 1984 working at eight pages per minute. Both products revolutionized their respective market places. Most importantly, the application of xerography was transformed from its analog imaging role to become part of the emerging digital imaging future.

- Canon introduced the concept of a low-cost personal copier with a customer-replaceable consumable cartridge in 1982. They creatively collected all of the high-maintenance elements of the xerographic processes into a customer-replaceable unit, thereby removing the need for frequent service. This would open a new market, and desktop copying and printing and would become a design standard for the industry.

- Organic photoreceptors [15,16] offered a breakthrough to a cost barrier, as they could be coated with much-lower-cost manufacturing, and they could be made into highly flexible belts rather than the selenium alloys, thus offering new printer architectures for digital color. In 1975, Kodak introduced its Ektaprint 100 copier/duplication based on an organic photoreceptor. Xerox followed suit in 1982 with its active-matrix organic photoreceptor in its 10-Series 1075 and 1090 duplicators.

- Canon, Hewlett Packard, Fuji-Xerox, and Xerox introduced very-high-quality digital color reprographic and printing devices that extended xerography into the color printing and graphics marketplace.

- The Total Quality Movement practiced by Japan manufacturers greatly improved the reliability of xerographic machine designs. Xerox improved its design and manufacture through its learning from Fuji-Xerox.

It is the nature of dominant designs that they are not simply replaced by an alternative technology. Their dominance will end with a radical transformation of the market they serve. A current example of the decline of a dominant design is analog silver halide photography and its iconic Kodak yellow box. The magic was in the chemistry of the film and its later processing. The analog film businesses of Kodak rapidly declined with the ascendency of a whole new paradigm of consumer photography: the digital camera, the smart phone, and inkjet printers. Dominant designs do have lifetimes.

Similar changes are appearing for prints on paper. The internet, personal computing devices, and social media are reshaping the world of publishing newspapers, magazines, and books. Challenges to the future use of print are seen in the processes of banking, legal, and other businesses.

Xerography is clearly in the mature stages of its lifetime. There still remain active literature creation and patent issuance every year, and there are at least a dozen companies producing products and services. Whether xerography prospers or fades into the sunset will depend on innovation extending its application into new markets.

References

1. OSA Annual Meeting, Detroit, Michigan, 22 October 1948.
2. R. M. Schaffert and C. D. Oughton, "Xerography: a new principle of photography and graphic reproduction, J. Opt. Soc. Am. **38**, 991–998 (1948).
3. J. H. Dessauer, *My Years at Xerox, The Billions Nobody Wanted* (Manor, 1975), p 31.
4. D. Owen, "Making Copies: at first, nobody bought Chester Carson's strange idea, but trillions of documents later, his invention is the biggest thing in printing since Gutenberg," Smithsonian Mag., August 2004.
5. J. H. Dessauer and C. H. Clark, *Xerography and Related Processes* (The Focal Press, 1965).
6. R. Schaffert, *Electrophotography* (The Focal Press, 1965).
7. M. Scharfe, *Electrophotography Principles and Optimization* (Research Studies Press, 1984), Vol. **3**.
8. J. Mort, *The Anatomy of Xerography, Its Invention and Evolution* (McFarland, 1989).
9. L. B. Schein, *Electrophotography and Development Physics* (Springer, 1992).
10. P. Borsenberger, *Organic Photoreceptors for Xerography* (Marcel Dekker, 1998).
11. C. Carlson, "Electrophotography," U.S. patent 2,297,691 (6 October 1942).
12. E. Garfield, "Citation index for scientific information," Science Watch **4**(2), 8 (1993).
13. J. M. Utterback, *Mastering the Dynamics of Innovation* (Harvard Business Press, 1996), pp. 23–26.
14. J. C. Urbach, T. S. Fisli, and G. K. Starkweather, "Laser scanning for electronic printing," Proc. IEEE **70**, 597–618 (1982).
15. M. Stolka, D. M. Pai, and J. E. Yanus, "Imaging system with a diamine charge transport material in a polycarbonate resin," U.S. patent 4,265,990 (5 May 1981).
16. M. Smith, M., C. F. Hackett, and R. W. Radler, "Overcoating the photoconductive layer with a charge transfer compound of aromatic polynuclear structure; xerograph," U.S. patent 4,282,298 (4 August 1981).